Local Corrections, Disparate Uses

Cooperation Spawns National Differential GPS

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This article reveals . . .

- Deployment of differential GPS equipment at decommissioned U.S. Air Force Ground Wave Emergency Network sites is saving about $750,000 per installation
- Through cooperative efforts between agencies, the National Geodetic Survey's Constantly Operating Reference Station (CORS) network has expanded to over 250 locations for precise surveying applications
- Interagency collaboration has led to expansion of the National Weather Service's Precipitable Water Vapor analysis project to more than 100 sites, greatly improving weather forecasting models

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The maritime differential GPS (DGPS) network operated by the U.S. Coast Guard (USCG) provides position accuracy and signal integrity needed to meet Coast Guard navigational requirements on inland rivers, harbors, and harbor approach areas up to a minimum of 20 nautical miles offshore of the continental United States, Puerto Rico, and selected portions of Alaska and Hawaii.

The network, which achieved Full Operational Capability (FOC) in March 1999, is a land-based augmentation system. It receives and processes signals from GPS satellites, calculates corrections from known positions, and broadcasts these corrections via a medium frequency (MF) transmitter to DGPS users in the broadcast site's coverage area. DGPS corrections bring accuracy to within 1 meter at the base of the tower, the signal experiences about 1 meter of further degradation for every 150 kilometers of distance from the broadcast site.

The Coast Guard's parent agency, the U.S. Department of Transportation (DOT), in collaboration with several federal and state agencies, is now expanding DGPS to cover the country's interior by coordinating the implementation of a Nationwide Differential GPS (NDGPS) network. After reviewing several options, DOT determined that the most efficient and cost-effective method of providing this expanded coverage would be to convert 47 obsolete low-frequency (LF) U.S. Air Force Ground Wave Emergency Network (GWEN) sites into NDGPS broadcast sites, based upon USCG standard DGPS site design. Reusing a GWEN site saves over $750,000 in construction and equipment costs when compared to constructing a new site. NDGPS utilizes essentially the same equipment configuration as the Coast Guard's DGPS — namely, two reference stations to calculate differential corrections, two integrity monitors to verify correction accuracy, and a transmitter to amplify the reference station correction data through an MF antenna. The unmanned broadcast sites are remotely monitored continuously by one of two DGPS control stations over a wide area network (WAN). In case either control station should fail, the other one can control all of the broadcast sites. In addition, the support baseline system at the USCG Command and Control Engineering Center (C2CEN) can double as an operational control station, providing another back-up option. When completed, this network will consist of 126 sites and will provide redundant standard DGPS C/A code corrections for a variety of users nationwide.

NDGPS is now operational with single-station coverage over about 80 percent of the continental United States and is expected to be fully operational with dual-station coverage throughout the continental United States and Alaska two years after capital funding is received. NDGPS provides a GPS integrity monitoring capability; it gives an alarm to users within 5 seconds of detecting a fault with the signal from any GPS satellite. NDGPS signals are available to any user who acquires the proper receiver, and there is no user fee.

Applications. NDGPS will replace older systems, supplement current ones, and obviate the need to build new ones. It will

- replace the existing U.S. Army Corps of Engineers (USACOE) microwave positioning system and reduce or eliminate the agency's requirements to develop independent DGPS networks for vessel navigation and positioning;
- provide raw GPS observables to the National Geodetic Survey (NGS) for use in the continuously operating reference stations (CORS). This is a national network

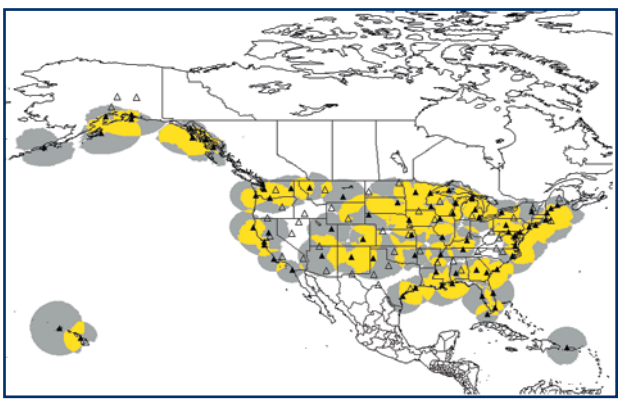

FIGURE 1 DGPS/NDGPS coverage, as of November 2001

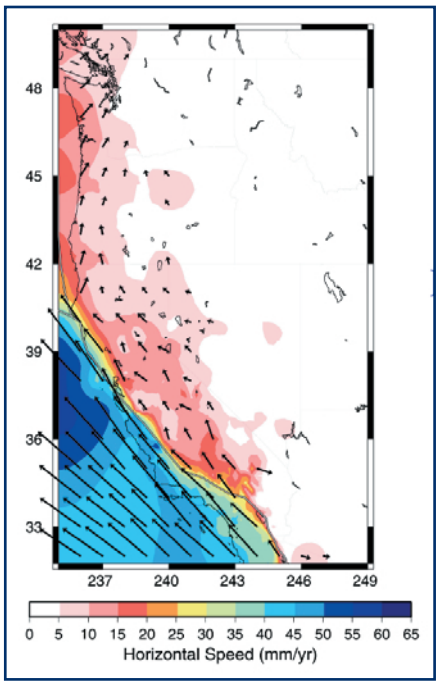

FIGURE 2 Plate tectonic measurements (UNAVCO)

of more than 250 geodetic-grade GPS receivers whose data are made publicly available for post-processing applications in receiver independent exchange (RINEX) format, for use in land surveys, geographic information systems (GIS), and environmental management;

- allow the National Oceanic and Atmospheric Administation (NOAA) to collect meteorological and GPS data for analysis by installing equipment at DGPS sites;
- allow the University Navstar Consortium (UNAVCO) to collect data for use in monitoring the deformation of tectonic plate boundaries;
- provide data to measure the amount of precipitable water vapor in the atmosphere above the sites;
- aid real time or post-process positioning applications, such as 911 response, automatic vehicle location (AVL) for public transit and other fleets, land-use planning, and tracking of hazardous materials.

History

In January 1996, the maritime DGPS system entered the Initial Operational Capability (IOC) phase in which signals from 51 DGPS broadcast sites were available for positioning and navigation. To achieve IOC, USCG co-located six of its broadcast sites on property owned by three USACOE districts. USCG performed site design, installed equipment, and erected antennas at these locations and continues to provide primary maintenance.

Later that year, the President assigned responsibility for all civilian GPS matters to DOT and charged it with implementing a national GPS augmentation system for terrestrial transportation. In January 1997, DOT formed the DGPS Executive Steering Group (ESG) and Policy and Implementation Team (PIT) to carry out this mandate. After opting to convert GWEN sites into DGPS broadcast sites, as mentioned earlier, and establishing and testing a successful prototype GWEN-to-DGPS conversion site at Appleton, Washington, the ESG called for the expansion of the Coast Guard's DGPS network into a nationwide system.

Besides the Coast Guard, the partnership for development and implementation of the DOT's NDGPS initiative includes six other agencies: the U.S. Air Force Air Combat Command (ACC), the Federal Railroad Administration (FRA), the Federal Highway Administration (FHWA), NOAA, USACOE, and the Office of the Secretary of Transportation (OST). USCG has also established partnerships with USACOE districts serving the Mississippi, Missouri, Arkansas, and Ohio rivers to facilitate the construction of eleven DGPS broadcast sites.

In February 1997, as the maritime DGPS system entered the Full Operational Capability (FOC) phase, USCG had 54 active DGPS broadcast sites for positioning and navigation and monitored these signals for correction accuracy.

Subsequently, USCG equipped ten of these sites with equipment from the National Weather Service's Forecast Systems Laboratory's GPS Surface Observing System (GSOS), to receive meteorological data as part of the Integrated Water Vapor demonstration project. This system measures water vapor content of the column of atmosphere above the broadcast site, significantly enhancing weather forecast models.

In 1999 and 2000, ACC transferred 54 GWEN sites and all GWEN spare parts to the Coast Guard. This significantly reduced NDGPS start-up costs while saving on USAF decommissioning costs.

Partnerships

Each participating agency plays a specific role in the NDGPS project.

- **OST** — Chairs the PIT
- **ACC** — Transfers GWEN assets to USCG for NDGPS use
- **USACOE** — Provides property management services and engineering design, construction, and environmental assessment services. In turn, implementation and use of DGPS will replace an existing USACOE microwave positioning system and will reduce or eliminate USACOE requirements to develop independent ultra-high frequency or very high frequency (UHF/VHF) DGPS networks for vessel navigation and positioning.
- **FRA** — Submits budget requests to Congress and advocates for them. Identifies and documents operational requirements and verifies performance requirements for railroad users.
- **FHWA** — Serves as the lead agency for environmental impact analyses and other environmental requirements. Identifies the number and general location of broadcast sites and their operating frequency. Performs coverage measurement analysis of each operational site. Coordinates with state and local governments to identify locations for new facilities.
- **USCG** — Manages real property; designs, installs, supports, and operates broadcast sites; and provides engineering expertise and support.
- **Tennessee Valley Authority (TVA)** — Provides civil engineering design and construction services. Refurbishes and stores USAF GWEN equipment and generator shelters.
- **NGS** — Provides geodetic coordinates for DGPS service, including monumentation, and assists USCG in the establishment, operation and evaluation of DGPS. In November 1997, NOAA and USCG agreed on the installation of surface meteorological sensors at ten DGPS broadcast sites for use in weather forecasting and climate monitoring. Specifically, NOAA will install GPS Surface Observing System (GSOS) equipment at ten DGPS sites and collect meteorological and GPS data for analysis. USCG will provide a location to install the equipment and primary power and data connectivity and will perform preventative and corrective maintenance. NOAA will install GSOS equipment at all NDGPS locations and at the remaining 44 maritime DGPS broadcast sites.
- **CORS Network** — CORS is a national network of over 250 sites containing geodetic-grade GPS receivers whose data are made publicly available for post processing applications. About one-third of these sites are DGPS and NDGPS reference stations. CORS code range and carrier phase data is used in post processing applications to calculate GPS-derived positions with accuracies that approach a few centimeters in three dimensions.
- **UNAVCO** is an international organization of more than 90 universities and research institutions performing geoscience projects utilizing GPS technology. It began a partnership with DGPS in November 2000 as part of the Plate Boundary Observation Project. This involves adding high-precision geodetic-quality antenna monuments and survey-quality choke ring antennas to the standard NDGPS reference station design to facilitate sub-centimeter positioning for tectonic plate monitoring over long baselines. The first UNAVCO-style pedestal and antennas were installed at the NDGPS site in Myton, Utah in February of this year.

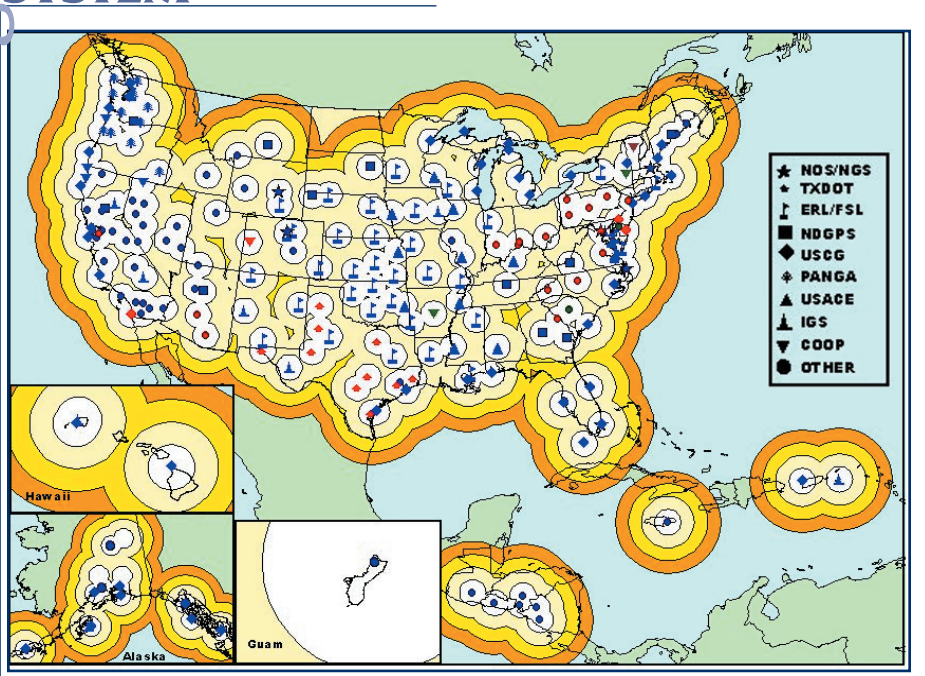

FIGURE 3 CORS coverage with 100-, 200-, 300-, and 400-kilometer radius, as of February 2001. Symbol color denotes sampling rates: brown, 1 second; red, 6 seconds; green, 15 seconds; and blue 30 seconds.

Sharing Resources

All of these partnerships between federal agencies to share equipment and/or resources date back to the inception of the maritime DGPS network, in 1995. Each partnership is formally documented with a Memorandum of Understanding (MOU) that details responsibilities for each party (see "Partnerships" sidebar).

As the maritime DGPS system expanded to nationwide coverage, new partnerships developed to provide network design (FHWA), environmental permitting (FHWA), antenna siting/GPS signal analysis (NGS), and developing the requirements and securing the funding for NDGPS (FRA).

These federal agencies also established partnerships with state and local agencies to acquire property and build new NDGPS broadcast sites.

Budget Process. To date, the NDGPS program has spent approximately $19 million in construction, engineering, and support. Each year, the FRA requests an NDGPS budget. Upon approval of funding by the Executive Branch, the NDGPS PIT then selects and prioritizes the number of sites to be converted or installed and the location for new NDGPS service, usually a specific town or city.

Network Design

Following the GWEN-to-DGPS conversion at Appleton, Washington, mentioned earlier, a preliminary NDGPS network design was completed by the National Telecommunications and Information Administration (NTIA). This analysis modeled various parameters — including numbers and locations of broadcast sites, effective radiated power, and transmit frequencies — and provided the basis for a network design for overlapping signal coverage across the continental United States.

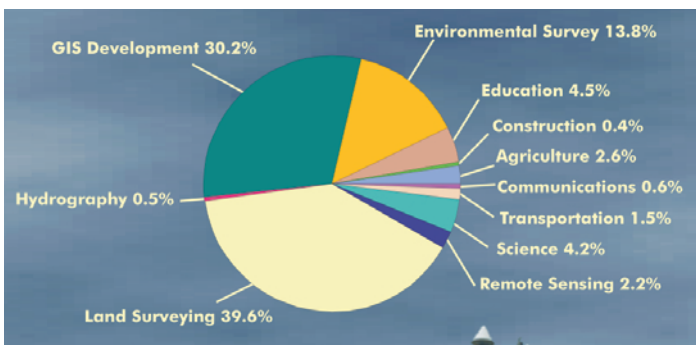

FIGURE 4 CORS applications

Antennas. GWEN was a highly redundant network of low frequency broadcast sites hardened to withstand electromagnetic pulse in case of nuclear attack. The reused transmit antenna at a converted GWEN site is 299 feet tall and has twelve Top Loading Elements (TLEs). This configuration yields an efficiency of approximately 55 percent when operated in the medium frequency band (285 kHz to 325 kHz) used in USCG DGPS signal propagation, compared to 15 percent efficiency for other USCG DGPS antennas. The superior NDGPS antenna efficiency translates into an expanded coverage area at the same transmit power, reducing the number of required broadcast sites to meet DGPS signal requirements in a specified area.

Additionally, the USCG has modified the GWEN 5000-watt, low-frequency pulsed transmitter to also operate at USCG DGPS frequencies. The USCG converted the transmitter to continuous wave operation and reconfigured the RF drive and power amplifier (PA) circuits for a maximum output power of 2500 watts. This allowed Coast Guard engineers to designate two of the four existing PA circuit card assemblies as installed spares.

To support the modified GWEN transmitters, the Air Force transferred to the USCG all the ready-for-issue and not ready-for-issue

Abbreviations

ACC	Air Force Air Combat Command
AVL	automatic vehicle location
C2CEN	USCG Command and Control Engineering Center
CORS	continuously operating reference stations
DGPS	differential GPS
DOT	U.S. Department of Transportation
ESG	Executive Steering Group
FHWA	Federal Highway Administration
FOC	Full Operational Capability
FRA	Federal Railroad Administration
GIS	geographic information systems
GSOS	National Weather Service's GPS Surface Observing System
GWEN	Ground Wave Emergency Network
IOC	Initial Operational Capability
LORAN	Long Range Navigation
MF	medium frequency
MOU	Memorandum of Understanding
NDBC	National Data Buoy Center
NDGPS	Nationwide Differential GPS
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administation
NTIA	National Telecommunications and Information Administration
OST	Office of the Secretary of Transportation
PIT	Policy and Implementation Team
RINEX	receiver independent exchange
TLEs	Top Loading Elements
UNAVCO	University Navstar Consortium
USACOE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
WAN	wide area network

Positive Train Control

NDGPS receivers placed on locomotives will calculate their location and speed. That information, transmitted back to a control center over the railroad's digital data network, will enable Positive Train Control (PTC). PTC systems integrate command, control, communications, and information systems for controlling train movements with safety, security, precision, and efficiency. PTC systems will greatly reduce the probability of collisions between trains, casualties to roadway workers, and overspeed accidents. PTC systems are comprised of continuous and accurate positioning systems such as NDGPS, digital data link communications networks, on-board computers with digitized maps on locomotives and maintenance-of-way equipment, in-cab displays, throttle-brake interfaces on locomotives, wayside interface units at switches and wayside detectors, and control center computers and displays. PTC systems may also interface with traffic planners, work order reporting systems, and locomotive health reporting systems.

Remote Intervention. PTC systems track the location of the trains, issue movement authorities to trains and can automatically enforce them, and continually update operating data systems with information on the location of locomotives, cars, and crews. PTC systems will permit a control center to stop a train should the locomotive crew be incapacitated and will provide improved and more reliable running time, higher asset utilization, and greater track capacity. They will assist railroads managing costs and in improving energy efficiency. Pilot versions of PTC were successfully tested a decade ago, but the systems were never deployed on a wide scale. Deployment of PTC on railroads is expected to begin in earnest later this decade.

Data links. Digital data link networks can move information to and from trains, switches, control centers, yards, stations, maintenance facilities, data systems, and customers. They will replace many of today's voice communications and will effectively increase the capacity of communications circuits and frequencies. With data link communications, the information is digitally coded and messages are discretely addressed to individual or multiple recipients. The Federal Communications Commission has assigned to the railroad industry 182 frequencies in the VHF band and 6 pairs of frequencies in the UHF band. The UHF frequencies are being used for digital communications, and some railroads have converted some of their assigned VHF frequencies from analog to digital communications. The conversion is expected to accelerate during the coming decade. — Richard Shamberger

Other Applications

CORS. Typical applications include land surveying, geographic information systems, and environmental surveys. Dedicated GPS reference station ports at each DGPS site provide raw GPS observables to a central NGS facility via the Coast Guard's LAN. These observables are then converted and organized into RINEX files for public distribution through the Internet (<http://www.ngs.noaa.gov/CORS/> or <ftp://www.ngs.noaa.gov/cors/>).

Plate Boundary Observation Project. The simplest view of plate tectonics implies that all deformation occurs across the boundary between idealized rigid plates. GPS data can show how this deformation varies in space and time and thereby help predict earthquakes.

GSOS. Water vapor is the source of clouds and precipitation and an ingredient in most major weather events. GPS-IPW vapor monitoring is a ground-based technique that measures the integrated (total column) of precipitable water vapor directly above a fixed site. This method uses DGPS reference stations and surface meteorological sensors to measure excess GPS signal delays caused by water vapor in the atmosphere. The first GSOS test system was installed at the National Weather Service in December 1997. Fifty-six additional GSOS systems have been installed and GSOS equipment will be added to the remaining 44 maritime DGPS sites. GSOS payloads are included in new NDGPS site installations. Thirteen sites have been completed to date. When NDGPS reaches full maturity and GSOS installations are completed as planned, the GSOS capable GPS-IPW network will increase to 180 locations.

Further Reading

"Implementing and Engineering an NDGPS Network," by David Wolfe, Connie Judy, Edward Haukkala, and David Godfrey, in *Institute of Navigation Proceedings, GPS-2000*, September 2000.

"The National and Cooperative CORS Systems in 2000 and Beyond," by Richard A. Snay, in *Proceedings of ION GPS-2000*, September 2000, pp. 55-58; posted at <http://www.ngs.noaa.gov/CORS/information4/>.

"2000 FSL/DD GPS-IPW Technical Review," by Department of Commerce, National Oceanic and Atmospheric Administration, and Forecast Systems Laboratory, posted at <http://www.gpsmet.noaa.gov/labreview/2000/GPS_Tech_Review_files/frame.htm>.

"An Investigation of the Use of Differential Global Positioning System Technology within State and Local Transportation Departments," by Rudy Persuad, James A. Arnold, and Monther Hammoudeh, posted at <http://www.tfhrc.gov/ library/states.htm>.

circuit boards it had in store. The USCG overhauled and tested these assemblies and placed them in its inventory stock to meet anticipated NDGPS supply requisitions.

New Site Selection

In the event a GWEN site is not available to provide the desired coverage area, the PIT establishes a new site. FHWA personnel begin this process by sending a standard site selection guide to a local state or federal agency representative, who then identifies potential sites within a 30- to 50-mile radius that meet the outlined criteria. The guide includes specifications for property size (11.2 acres), environmental concerns, availability of power and telephone service, and the impact of any nearby objects that could mask the GPS antennas or cause multipath interference. Upon completion of this stage of the site selection process, collaborating agencies have narrowed the number of potential sites down to two or three. The results are forwarded to C2CEN, which sends an engineering representative to visit these sites for a final survey before choosing one.

Future Initiatives. As new NDGPS sites come on line, the Coast Guard is evaluating co-locating them with its Long Range Navigation (LORAN) transmitting sites. As with the use of pre-existing GWEN sites, this co-location project will provide significant savings in land acquisition and construction costs, and consolidate maintenance costs for two radionavigation programs. Due to LORAN's critical timing and pulse shaping requirements, the engineering approach currently under evaluation is to use an existing top-load element (TLE) guy wire from the LORAN tower as an inverted L long wire antenna for DGPS signal propagation.

Conclusion

Federal and state agencies have demonstrated their ability to cooperate to build a multi-purpose DGPS that meets a varied set of user requirements. They achieved this through partnerships that respect each organization's mission, customer base, and skill sets.

Manufacturers

For the USCG's maritime and nationwide DGPS system **Ashtech Precision Products Division** of Thales Navigation supplies the GPS reference stations and antennas, **Trimble Navigation Limited** supplies the DGPS integrity monitors and antennas, and **Cisco Systems Inc.** supplied the data communication routers. **Southern Avionics Company** supplied the 1000W medium-frequency radio transmitters used at maritime DGPS broadcast sites. NOAA's **National Data Buoy Center** custom designed and fabricated GSOS equipment.